PRECISION MEASUREMENT OF THE HIGGS BOSON MASS AND SEARCH FOR DILEPTON MASS RESONANCES IN H $\rightarrow 4\ell$ DECAYS USING THE CMS DETECTOR AT THE LHC

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
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Abstract of Dissertation Presented to the Graduate School
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The mass of the Higgs boson is measured in the $\mathrm{H} \to \mathrm{ZZ}^* \to 4\ell$ ($\ell = \mathrm{e}, \mu$) decay channel and is found to be TODO:MASS—the world's best measurement to date. The data for the measurement were produced from proton-proton (pp) collisions at the Large Hadron Collider with a center-of-mass energy of 13 TeV during Run 2 (2016–2018), corresponding to an integrated luminosity of $137.1\,\mathrm{fb}^{-1}$, and were collected by the Compact Muon Solenoid experiment. This measurement uses an improved analysis technique in which the final state muon tracks are constrainted to originate from the primary pp vertex. Using data sets from the same run, a search for low-mass dilepton resonances in Higgs boson decays to the 4ℓ final state is also conducted. No significant deviation from the standard model prediction is observed.

CHAPTER 1
INTRODUCTION

Motivation—why you should read this thesis What is this thesis about? The universe, while overwhelmingly vast, is comprised of a curiously small number of unique elementary particles. These particles—and their interactions with each other—are accurately described by the standard model (SM) of particle physics.

A major shortcoming of the SM was its inability to predict the masses of these particles.

The SM was not able to predict the masses of these particles until 1964 when the Brout-Englert-Higgs mechanism suggested that It wasn't until 1964 that the Brout-Englert-Higgs mechanism gave a self-consistent way to : by breaking the electroweak gauge symmetry of the vacuum would give rise to non-zero masses of the weak gauge bosons. This would yield a secondary effect too: there should exist a fundamental scalar boson which is the quantum of the so-called "Higgs field". On July 4th, 2012, this Higgs boson was discovered.

This dissertation presents the world's most precise measurement of the Higgs boson mass (m_{H}) to date, using proton-proton collision data from the LHC Run 2, collected and analyzed by the CMS Experiment. The value of m_{H} has been measured previously TODO:CITE LOTS OF PEEPS [2] but it is important to always strive for lower uncertainties (i.e. to increase the precision) on the mass value, since the very stability of our universe is theoretically dependent on it, as shown in Fig. 1-1. Furthermore, the value of m_{H} sets limits on the masses of the other particles.

The measurement of m_{H} presented in this dissertation utilizes the following improvements compared to previous measurements:

- more analyzed data (TODO:LATEXCOMMAND cf. $\mathcal{L}(2016) = 35.9\,\mathrm{fb}^{-1}$ vs. $\mathcal{L}(\mathrm{Run2}) = 137.1\,\mathrm{fb}^{-1}$)
- Previously, only 3 final-state categories (4μ, 4e, $2\mathrm{e}2\mu$) have been separately analyzed; in this analysis, the $2\mathrm{e}2\mu$ category is further split up into $2\mathrm{e}2\mu$ and $2\mu2\mathrm{e}$, depending on into which flavors of leptons the Z_1 decayed (). This is important because these mixed-flavor final states have different kinematical properties: they have different peak widths (instrumental resolutions), different signal efficiencies, and different relative levels of reducible background.
- Ultra-Legacy (UL) reconstruction is used for muon, electron, photon, and jet tracks. This signficantly improves electron momenta, while improving the other particle momenta a little less so.

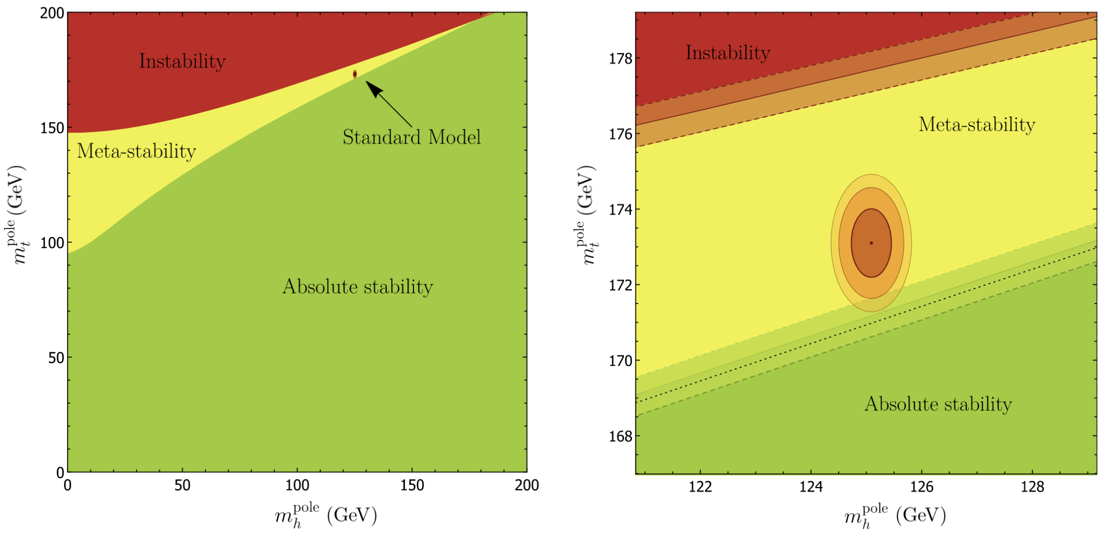

Figure 1-1. (Left) Theoretical stability regions of our universe based on the pole masses of the top quark $\left(m_t^{\text{pole}}\right)$ and Higgs boson $\left(m_h^{\text{pole}}\right)$. (Right) A closeup of the SM region of the left plot. The contours represent the 68%, 95%, and 99% confidence levels based on the experimental uncertainties of m_t^{pole} and m_h^{pole}. Plots taken from [1] and units added to all axes.

- The measurements of muon $p_{\rm T}$ are improved by constraining the muon tracks to originate from the interaction vertex (also called a *vertex constraint*).
- TODO:REWORD A correlation between $\sigma_{m_{4\ell}}$ and $\mathcal{D}_{\text{bkg}}^{\text{kin}}$ is avoided by When extracting the value of $m_{\rm H}$ in past measurements, a 3D pdf $\left(m_{4\ell}, \mathcal{D}_{\text{bkg}}^{\text{kin}}, \sigma_{m_{4\ell}}\right)$ was built into a factorized form $f\left(m_{4\ell}, \sigma_{m_{4\ell}} \,\middle|\, m_{\rm H}\right) \cdot g\left(\mathcal{D}_{\text{bkg}}^{\text{kin}} \,\middle|\, m_{4\ell}\right)$, which was later found to contain an existing correlation between $\mathcal{D}_{\text{bkg}}^{\text{kin}}$ and $\sigma_{m_{4\ell}}$. To account for this correlation, now the events are split into 9 categories based on the per-event *relative* mass uncertainty $\left(\frac{\sigma_{m_{4\ell}}}{m_{4\ell}}\right)$ and, for each, a 2D pdf $\left(m_{4\ell}, \mathcal{D}_{\text{bkg}}^{\text{kin}} \,\middle|\, m_{\rm H}\right)$ is built.
- The uncertainties on lepton momentum scale ($p_{\rm T}^{\rm e,\mu}$) are reduced, thanks to a more detailed analysis of the corresponding systematic uncertainties. This has the additional effect of significantly reducing the uncertainty on the per-event four-lepton mass resolution.

This dissertation is organized into the following chapters: Chapter 1 (*this chapter*) discusses the importance and motivation for measuring the mass of the Higgs boson; Chapter **??** introduces the standard model (SM) of particle physics and its mathematical framework, including the Brout-Englert-Higgs (BEH) mechanism; Chapter **??**; Chapter **??**; Chapter **??**; Chapter **??**; Finally, Chapter **??**.

REFERENCES

[1] Anders Andreassen, William Frost, and Matthew D. Schwartz. Scale-invariant instantons and the complete lifetime of the standard model. *Phys. Rev. D*, 97:056006, Mar 2018. doi: 10.1103/PhysRevD.97.056006. URL https://link.aps.org/doi/10.1103/PhysRevD.97.056006.

[2] Measurements of properties of the Higgs boson decaying into four leptons in pp collisions at sqrts = 13 TeV. Technical report, CERN, Geneva, 2017. URL http://cds.cern.ch/record/2256357.